

DEVELOPMENT OF ENGINE MANAGEMENT SYSTEM FOR MODIFIED  
DIESEL ENGINE FUELLED BY  
COMPRESSED NATURAL GAS (CNG)

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## ABSTRACT

Air pollution is a serious global problem. Most country uses diesel engine, which produces substantial amount of emission, for the transportation sector. That is why development of green car is important to solve this problem. Compressed natural gas (CNG) as fuel to run diesel engine is one solution to decrease emission. This thesis deals with the finding of the best air-fuel ratio to be input into the Engine Control Unit (ECU) so that the ECU can manage the engine properly. Simulation of experiment of effect of variable AFR at variable manifold pressure for fixed RPM is run using GT-Power software. Hence a modified single cylinder diesel engine to run on CNG is studied and parameters are taken from the engine to be input into the template library of GT-Power software. In this project, the studied RPM is from 800 RPM to 3000 RPM with increment of 200 RPM. The manifold pressure range from 0.25 Bar to 1.00 Bar with increment of 0.05 Bar. As for the air-fuel ratio (AFR), the range is from 12.5 to 21. The results obtained from the simulation are viewed using GT-Post. The data are then transfer to Microsoft Excel to plot out the graph. From the graph, the best AFR is determined and input into the AFR table of Megatune software and burn into the ECU. Result shows that the engine operate well on lean mixture for all condition. Engine performance curve plotted from the result shows that the trend of curve is the same for all manifold pressure, the only difference is as manifold pressure increase the power output also increases. From published reports and books, it is stated that lean burning of air fuel mixture increases fuel conversion efficiency. Also optimum efficiency from natural gas is obtained when burnt in a lean mixture. It is concluded that the AFR table is successfully inputted with the best AFR at different RPM and manifold pressure.

## ABSTRAK

Pencemaran udara merupakan masalah global yang serius. Kebanyakan negara menggunakan mesin diesel yang menjana banyak gas pencemaran untuk sektor pengangkutan mereka. Oleh sebab itu penyelidikan kereta 'green car' adalah penting untuk menyelesaikan masalah ini. Gas Semulajadi yang Dimampat (CNG) sebagai bahan bakar untuk mesin diesel merupakan satu penyelesaian untuk mengurangkan gas pencemaran. Thesis ini dibuat untuk mencari nisbah antara udara dan minyak yang terbaik untuk dimasukkan ke dalam Unit Pengawalan Mesin (ECU) supaya Unit Pengawalan Mesin (ECU) dapat menguruskan mesin dengan baik. Simulasi untuk ujian kesan pembolehubah nisbah antara udara dan minyak dan pembolehubah tekanan kebumuk untuk satu mesin revolusi (RPM) yang tetap dibuat dengan menggunakan perisian GT-Power. Oleh itu, modifikasi ke atas mesin diesel satu silinder untuk membakar Gas Semulajadi yang Dimampat (CNG) dikaji dan ukuran mesin yang diambil dimasukkan ke dalam perpustakaan templat perisian GT-Power. Dalam project ini, mesin revolusi (RPM) yang dikaji ialah dari 800 RPM ke 3000 RPM dengan kenaikan 200 RPM. Tekanan kebumuk pula meliputi tekanan 0.25 Bar hingga 1.00 Bar dengan kenaikan 0.05 Bar. Untuk nisbah udara kepada minyak pula, liputannya dari 12.5 ke 21. Keputusan yang diperolehi dari simulasi tersebut dilihat dengan menggunakan perisian GT-Post. Data tersebut kemudian akan dipindah ke Microsoft Excel untuk melukis graf. Dari graf, nisbah udara kepada minyak (AFR) yang terbaik ditentukan dan dimasukkan ke dalam jadual nisbah udara kepada minyak (AFR) dalam perisian Megatune dan dibakar ke dalam Unit Pengawalan Mesin (ECU). Keputusan menunjukkan bahawa mesin tersebut beroperasi baik pada campuran ramping untuk semua keadaan. Graf prestasi mesin yang diplot menunjukkan bahawa gaya semua graf pada semua tekanan kebumuk yang diuji adalah sama, perbezaan yang ketara ialah bila tekanan kebumuk naik kuasa yang dijana juga menaik. Dari laporan dan buku yang diterbitkan, adalah dinyatakan bahawa pembakaran ramping bagi campuran udara minyak meningkatkan kecekapan penukaran bahan bakar. Di samping itu, kecekapan optimum dari gas semulajadi dicapai apabila campuran ramping berlaku. Jadi, dapat disimpulkan bahawa dengan berjaya jadual nisbah udara kepada minyak (AFR) telah diisi dengan nisbah udara kepada minyak (AFR) yang terbaik pada mesin revolusi (RPM) dan tekanan kebumuk yang berbeza.

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**LIST OF SYMBOLS**

$\varepsilon$	Compression ratio
$V_h$	Swept volume
$V_C$	Compression volume
$\phi$	Equivalence ratio
$P$	Pressure
$V$	Volume
$m$	Mass
$R$	Ideal gas constant
$T$	Absolute temperature

**LIST OF ABBREVIATIONS**

AFR	Air fuel ratio
BDC	Bottom Dead Centre
BHP	Brake Horse Power
CNG	Compressed Natural Gas
ECU	Engine Control Unit
MAP	Manifold Absolute Pressure
NGC	Natural Gas Car
NGV	Natural Gas Vehicle
NTC	Negative Temperature Coefficient
PTC	Positive Temperature Coefficient
RPM	Revolutions per Minute
TDC	Top Dead Centre
TPS	Throttle Position Sensor

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 INTRODUCTION**

This chapter gives a short description of the project background including several approaches. It then introduces objectives, scopes, problem statement of this project which is the development of engine management system for modified diesel engine fuelled by compressed natural gas (CNG).

#### **1.2 PROJECT BACKGROUND**

The problem of air pollution around the globe is real and serious. In most countries, the transportation sector uses mostly diesel-powered engines, which are heavy polluters. That is why 'green' cars are important. But designing, developing and marketing "green" cars is not an easy task and also to correctly convert a diesel engine to a low-polluting CNG or LPG engine is costly, technologically challenging and timely. That is why diesel-powered vehicles are still used till this day and fossil fuels still account for almost 75 percent of the world's energy consumption.

But till recent years, due to diesel price hike, concerns of increasing harmful emission and also the near depletion of crude oil reserve, vehicles that run on alternative fuel source is becoming increasingly important because they are more fuel efficient and environmentally friendly. It is noticeable that most of these countries that use diesel-

powered engine vehicles import the diesel fuel they use and the fuel are expensive due to price hike. Most of them have large reserves of natural gas but no technology to use it in engines. The conversion of diesel engines to natural gas would decrease the country's dependence on imported foreign fuel and help them utilize the abundant natural gas resources.

### **1.3 PROBLEM STATEMENT**

Modification is done to a diesel engine to run on CNG. The modification done will enabled the diesel engine to run on CNG but for the engine to run with high efficiency, hence more economic, and produce less emission, the engine will need to be managed properly. So the need of Engine Controlling Unit is the key component to manage the operation of the modified diesel engine properly. Hence, tuning the ECU is the purpose of this project so that the engine can be managed to run smoothly and efficiently.

### **1.4 OBJECTIVE**

The objectives of this project are:

- (i) To modify a diesel engine to run on CNG, that is more economical and produces less emission.
- (ii) To tune the ECU so that the ECU can manage the operation of the engine to run efficiently and produce less emission.
- (iii) To obtain optimum value for air fuel ratio (AFR).

### **1.5 PROJECT SCOPE**

In order to achieve the objectives of the project, the following scopes are listed:

- (i) Tuning will be done on a Engine Control Unit (ECU).

- (ii) ECU used is Megasquirt II version 3.
- (iii) Tuning software used is Megatune version 2.55.
- (iv) Engine used is a single cylinder diesel engine with capacity of 400cc.
- (v) Parameters monitored by the ECU:
  - a) Dependent parameters:
    - i. Pressure of intake manifold, the in-cylinder pressure, the exhaust pressure.
  - b) Independent parameters:
    - i. The speed of the engine, which is the RPM.
- (vi) From 800 rpm to 3000 rpm, with increment of 200 rpm, variable AFR is tested to obtained best engine power at variable manifold pressure which is from 0.25 Bar to 1 Bar with increment of 0.05 Bar.
- (vii) Simulation for obtaining best AFR by using GT-Power version 6.1.0.

## **1.6 SUMMARY**

Chapter 1 discussed briefly about the project's problems statement, objectives and the scope of the project, which will be conducted to achieve the development of engine management system for modified diesel engine fuelled by compressed natural gas (CNG). This chapter is as a fundamental for this project and as a guidelines to complete this project research.



## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 INTRODUCTION**

This chapter will discuss about how a diesel engine works and also how a CNG engine works. The differences of working principle and components of both engine is compared to determine what modifications are needed to convert a diesel engine to run on CNG. The Engine Management System is also studied to recognize its working principle and also about the sensors the system uses to manage the operation of the engine. The diesel fuel and CNG fuel is compared also to recognize both fuel's properties, advantage and disadvantage.

#### **2.2 DIESEL ENGINES**

Diesel engines are internal combustion engine. They are designed to convert the chemical energy available in fuel into mechanical energy. This mechanical energy moves pistons up and down inside cylinders. The pistons are connected to a crankshaft, and the up-and-down motion of the pistons, known as linear motion, creates the rotary motion needed to turn the wheels of a car forward. In diesel engine, the air is compressed first and then the fuel is injected. Diesel engines have high compression ratio, a compression ratio of 14:1 to as high as 25:1, which produces a pressure range of about 30 bars to 50 bars. When air is compressed to this pressure range it will be heated to about 550° C to 900° C, which is high enough to ignite the injected fuel. (Bosch, 2005)

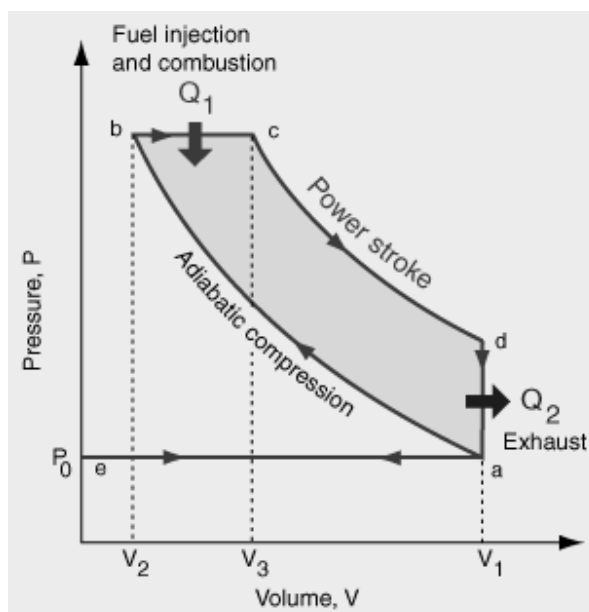
### 2.2.1 Four Stroke Cycle (Bosch, 2005)

The diesel engine uses a four-stroke combustion cycle. The four strokes are:

- (i) Intake stroke - The intake valve opens up, letting in air and moving the piston down. When the piston reaches Bottom Dead Center (BDC), the cylinder capacity is at its greatest ( $V_h + V_c$ ).
- (ii) Compression stroke - The inlet valve and outlet valve now closed. The piston moves back up and compresses the air to the degree determined by the engine's compression ratio and the air is heated up in the process. When compression stroke is almost complete, the fuel injection system injects fuel at high pressure into the hot, compressed air.
- (iii) Ignition stroke – After the ignition lag (a few degree of crank shaft rotation) has elapsed, the ignition stroke begins. The finely atomized and easily combustible diesel fuel spontaneously ignites and burns due to the heat of the air. As a result, the pressure in the cylinder rises up and the pressure force pushes the piston downwards.
- (iv) Exhaust stroke – Before the piston reaches bottom dead center, the exhaust valve opens and the exhaust gas flow out of the cylinder. As the piston moves back to the top again, it pushes out the remaining exhaust gas.

### 2.2.2 Diesel Cycle

In the diesel engine, air is compressed adiabatically with a compression ratio typically between 14 and 25. This compression raises the temperature to the ignition temperature of the fuel mixture which is formed by injecting fuel once the air is compressed. The ideal air-standard cycle is modeled as a reversible adiabatic compression followed by a constant pressure combustion process, then an adiabatic expansion as a power stroke and an isovolumetric exhaust. A new air charge is taken in at the end of the exhaust. Figure 2.1 presents the processes as described. (HyperPhysics, Undated)



**Figure 2.1:** Air standard diesel engine cycle

Source: HyperPhysics (Undated)

### 2.2.3 Direct Injection

Diesel engines use direct fuel injection -- the diesel fuel is injected directly into the cylinder. The injector on a diesel engine is its most complex component and has been the subject of a great deal of experimentation -- in any particular engine, it may be located in a variety of places such as directly above the combustion chamber or below the intake valve. The injector has to be able to withstand the temperature and pressure inside the cylinder and still deliver the fuel in a fine mist. Getting the mist circulated in the cylinder so that it is evenly distributed is also a problem, so some diesel engines employ special induction valves, pre-combustion chambers or other devices to swirl the air in the combustion chamber. The design of piston crown such as dish-shaped, dome-shaped and intricate contour also helps to improve swirl in combustion chamber. As a result, this will improve the ignition and combustion process. (Marshall, 2009)

### 2.2.4 Compression

Rudolf Diesel theorized that higher compression leads to higher efficiency and more power. This happens because when the piston squeezes air with the cylinder, the air becomes concentrated. Diesel fuel has high energy content, so the likelihood of diesel reacting with the concentrated air is greater. Another way to think of it is when air molecules are packed so close together, fuel has a better chance of reacting with as many oxygen molecules as possible. (Bosch, 2005)

The compression ratio,  $\varepsilon$ , of a cylinder results from its swept volume,  $V_h$ , and its compression volume,  $V_c$ , thus: (Bosch, 2005)

$$\varepsilon = \frac{V_h + V_c}{V_c} \quad (2.1)$$

The compression ratio of an engine has a decisive effect on the following:

- (i) The engine's cold-starting characteristic
- (ii) The torque generated
- (iii) The fuel consumption
- (iv) How noisy the engine is
- (v) The pollutant emissions

## 2.3 COMPRESSED NATURAL GAS ENGINE

The engine of a Natural Gas Car (NGC) or a Natural Gas Vehicle (NGV) works in a way that is very similar to that of a standard internal combustion engine that runs on gasoline. It uses the cylinder "sparkplug" piston concept to generate motion from controlled fuel combustion. They differ mainly on the flammability, volume, and ignitability of the fuel used. (Tech-FAQ, 2009)

### 2.3.1 Four Stroke Cycle

The CNG engine uses a four-stroke combustion cycle. The four strokes are:

- (i) Intake stroke - The inlet valve open, the piston first descends on the intake stroke. An ignitable mixture of gasoline vapor and air is drawn into the cylinder by the partial vacuum thus created.
- (ii) Compression stroke - The mixture is compressed as the piston ascends on the compression stroke with both valves closed.
- (iii) Ignition stroke –As the end of the stroke is approached, the charge is ignited by an electric spark. The power stroke follows, with both valves still closed and the gas pressure, due to the expansion of the burned gas, pressing on the piston head or crown to drive the piston down.
- (iv) Exhaust stroke –During the exhaust stroke the ascending piston forces the spent products of combustion through the open exhaust valve. The cycle then repeats itself.

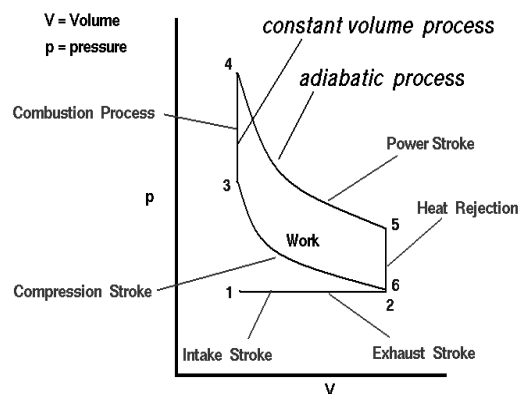
Each cycle thus requires four strokes of the piston—intake, compression, power, and exhaust—and two revolutions of the crankshaft. (Britannica, Undated)

### 2.3.2 Otto Cycle

The Otto Thermodynamic Cycle is used in spark ignition internal combustion engines. Figure 2.2 shows a p-V diagram of the ideal Otto cycle. Using the engine stage numbering system, we begin at the lower left with Stage 1 being the beginning of the intake stroke of the engine. The pressure is near atmospheric pressure and the gas volume is at a minimum. Between Stage 1 and Stage 2 the piston is pulled out of the cylinder with the intake valve open. The pressure remains constant, and the gas volume increases as fuel/air mixture is drawn into the cylinder through the intake valve. Stage 2 begins the compression stroke of the engine with the closing of the intake valve. Between Stage 2 and Stage 3, the piston moves back into the cylinder, the gas volume decreases, and the pressure increases

because work is done on the gas by the piston. Stage 3 is the beginning of the combustion of the fuel/air mixture. The combustion occurs very quickly and the volume remains constant. Heat is released during combustion which increases both the temperature and the pressure, according to the equation of state. Stage 4 begins the power stroke of the engine. Between Stage 4 and Stage 5, the piston is driven towards the crankshaft, the volume is increased, and the pressure falls as work is done by the gas on the piston. At Stage 5 the exhaust valve is opened and the residual heat in the gas is exchanged with the surroundings. The volume remains constant and the pressure adjusts back to atmospheric conditions. Stage 6 begins the exhaust stroke of the engine during which the piston moves back into the cylinder, the volume decreases and the pressure remains constant. At the end of the exhaust stroke, conditions have returned to Stage 1 and the process repeats itself.

During the cycle, work is done on the gas by the piston between stages 2 and 3. Work is done by the gas on the piston between stages 4 and 5. The difference between the work done by the gas and the work done on the gas is the area enclosed by the cycle curve and is the work produced by the cycle. The work times the rate of the cycle (cycles per second) is equal to the power produced by the engine. (NASA, 2008)



**Figure 2.2:** Ideal Otto cycle

Source: NASA (2008)

## **2.4 ENGINE MANAGEMENT SYSTEM**

Engine Management System is the Engine Control Module, or the "brain", that controls the fuel supply and the ignition by combining the two separate functions into one main system. The brain controls the whole of the combustion process, making the engine more efficient and less polluting. (Motorsave, 2006)

The Engine Control Unit (ECU) uses closed-loop control, a control scheme that monitors outputs of a system to control the inputs to a system, managing the emissions and fuel economy of the engine. The system works by using sensors located on the engine. These sensors measure parameters of the engine such as the speed and the temperature of the intake air, coolant temperature, amount of oxygen in the exhaust, the speed and position of the crankshaft and etc. These information is then gathered and the ECU performs millions of calculations each second, including looking up values in tables, calculating the results of long equations to decide on the best spark timing and determining how long the fuel injector is open.. This makes the engine more efficient, economical, less polluting and more powerful. The fuel is injected into the engine at high pressure and at a calculated rate by electronically controlled injectors. The ignition is also controlled by the brain to allow for movement in ignition timing which will produce better combustion so more of the fuel entering the engine can be burnt. (Karim, 2009)

## **2.5 SENSORS**

Sensors register operating states such as engine speed. They convert physical quantities such as pressure or chemical quantities such as exhaust gas concentration into electric signals. (Bosch, 2005)

### **2.5.1 Engine Speed Sensor**

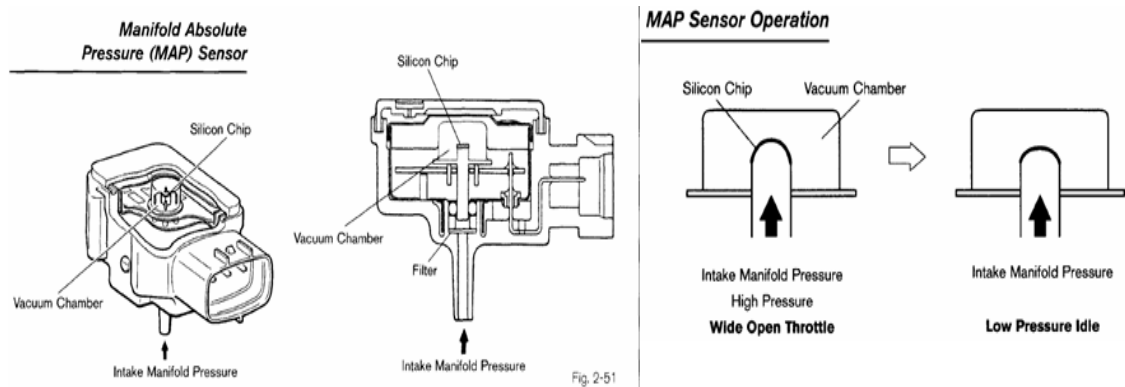
Engine speed sensors are used in Motronic systems for measuring the engine speed and determining the crankshaft position.

The Inductive Speed Sensor is one type of engine speed sensor. The sensor is mounted directly opposite a ferromagnetic trigger wheel where both are separated by a narrow air gap in the range of 0.5mm to 1.8mm. The sensor works through magnetic induction. The teeth of the trigger wheel will concentrate the magnet's leakage flux while the gap will weaken the magnetic flux. When the trigger wheel rotates, the magnetic-flux changes induce sinusoidal output voltage in the coil which is proportional to the rate of change of the flux and thus the engine speed. The speed range of the inductive speed sensor is 20 to 7000 rpm. (Bosch, 2005)

### **2.5.2 Manifold Absolute Pressure Sensors**

Manifold Absolute Pressure Sensors or MAP Sensors, are used to measure inlet manifold 'pressure' to give an indication of engine load. These sensors are generally used in "Speed/Density" or "Manifold Pressure Controlled" engine management systems that do not use an Air Flow/Mass Sensor. The MAP sensor measures "Absolute" pressure not "Gauge" pressure, so normal atmospheric pressure is a value of 1 bar. In the MAP sensor there is a silicon chip mounted inside a reference chamber. On one side of the chip is a reference pressure. This reference pressure is either a perfect vacuum or a calibrated pressure, depending on the application. On the other side is the pressure to be measured. When the silicon chip flexes with the change in pressure, the electrical resistance of the chip changes. These changes in resistance alter the voltage signal. The ECU interprets the voltage signal as pressure and any change in the voltage signal means there was a change in pressure. Intake manifold pressure is directly related to engine load. Knowing what the intake manifold pressure is, the ECU can calculate how much fuel to inject, when to ignite the cylinder and other functions. The MAP sensor is located either directly on the intake manifold or it is mounted high in the engine compartment and connected to the intake manifold with vacuum hose. The MAP sensor uses a perfect vacuum as a reference pressure. The difference in pressure between the vacuum pressure and intake manifold pressure changes the voltage signal. The MAP sensor converts the intake manifold pressure into a voltage signal. Figure 2.3 shows how a MAP sensor looks like and how it operates. (Toyota Motor Sales, Undated)





**Figure 2.3:** Manifold Absolute Pressure Sensor

Source: Toyota Motor Sales (Undated)

### 2.5.3 Intake Air Temperature Sensor

The purpose of an intake air temperature sensor is to help the computer calculate air density. A change in temperature changes the resistance in the sensor. Simply stated, the higher the air temperature gets the less dense the air becomes. As the air becomes less dense the computer knows that it needs to lessen the fuel flow. If the fuel flow was not changed the engine would become rich, possibly losing power and consuming more fuel. (Free Engine Info, Undated)

### 2.5.4 Coolant Temperature Sensor

Coolant temperature sensor changes resistance as the engine's coolant temperature changes. The sensor's output is monitored by the engine computer to regulate various ignition, fuel and emission control functions, variable valve timing, transmission shifting and to turn the radiator-cooling fan on and off as needed. In the PTC (Positive Temperature Coefficient) type of sensor, ohms go up with temperature. In the NTC (Negative Temperature Coefficient) type, resistance goes down as heat goes up. Figure 2.4 shows how a Coolant Temperature Sensor looks like. (Matthew, 2002)